





# Comparative Analysis of PWM Methods for Three Level Neutral Point Clamped Inverter

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**Abstract.** In present scenario renewable energy sources are crucial and they taking lead to supply power to the consumers. These renewable energy sources mostly generate dc power, which are to be converted into alternating supply for consumer's use. So there is an impelling need of inverter to convert direct current supply into alternating supply. These inverters are classified into numerous types and depending upon application, the type of inverter is used. In general, a normal inverter will produce square wave output where as a multi-level Inverter will produce staircase waveform which is nearer to sinusoidal. By the level upgrading, the output waveform is very near to the pure sine nature. In this paper, a comparative analysis between the basic Sine PWM and advanced Third Harmonic Injection method for a three level Neutral Point Clamped Inverter (NPC).

**Keywords:** Neutral Point Clamped (NPC) Inverter · Pulse Width Modulation (PWM) · Third Harmonic Injection PWM (THIPWM) · Sine PWM (SPWM)

## 1 Introduction

The multilevel inverters have been highly penetrated into power industry due to their remarkable features such as modularity, enhanced power quality, reactive power compensation and need of fewer filters etc. The power and voltage rating of a MLI can be increased by proper selection of configuration. The number of levels being increased decreases the voltage strains on the devices, boosts the inverter's ability to handle more power, and considerably enhances the output power quality. Three general categories can be used to classify multilevel inverters [1, 2]. They are the Neutral Point Clamped Multilevel Inverter (NPCMLI) or Diode Clamped Multilevel Inverter, the Flying Capacitor Multilevel Inverter (FCMLI) and the Cascaded H-Bridge Multilevel Inverter. The three-level Diode Clamped multilevel inverter (NPCMLI), which was suggested by Nabae, Takahashi, and Akagi in 1981. By using the appropriate Pulse Modulation Techniques (PWM), these converters' output can be significantly altered [3]. Conventionally, sinusoidal pulse width modulation (SPWM) [4] has been applied to regulate the inverter

output voltage. Even though, the SPWM technique is simple to implement, its DC bus utilization ratio is 79%. Further, space vector pulse width modulation (SVPWM) [5–8] techniques are used to control the inverter which improved the DC bus utilization by 15.5%. However, the implementation of SVPWM sophisticated digital controller to perform various calculations.

In this paper, third harmonic injection pulse width modulation (THIPWM) in which benchmark wave is a combination of sinusoidal signals with fundamental and third harmonic frequency is used to control the three level NPCMLI. Implementation of THIPWM is simple and provides additional 15.5% DC bus utilization which is similar performance that of SVPWM.

### Sinusoidal Pulse Width Modulation (SPWM):

The sine wave is used as the reference wave and the high frequency triangle wave is used as the carrier wave in the sinusoidal PWM approach.

### Third Harmonic Injection Pulse Width Modulation (THIPWM):

The fundamental and third harmonic components of the sinusoidal signal are added to create the reference wave in the Third Harmonic Injection PWM technique, and the high frequency triangle wave is used as the carrier wave.

## 2 Sinusoidal PWM For Three-Level Inverter

The sinusoidal PWM for three-level NPC inverter shown in Fig. 1 is implemented on the basis of unipolar switching scheme. Comparatively the implementation of sine PWM for three-level inverter is little bit difficult to that of two-level inverter. The Table 1 describes the operation of the sine PWM for three-level inverter. The carrier triangle wave has a frequency of 1050 Hz and the benchmark sine wave has a frequency of 50 Hz. Compared to the conventional MLIs, there are different configurations are been developed recently. But the traditional converters are more feasibility than these non-conventional converters [9, 10] (Fig. 1).

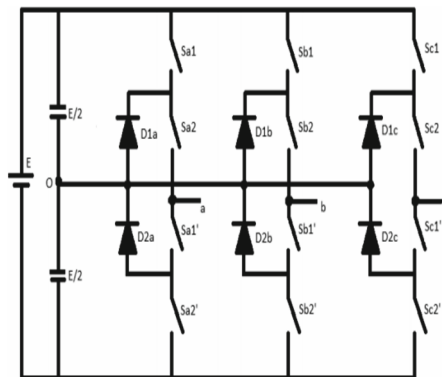


Fig. 1. Three Level NPC Inverter [11]

**Table 1.** Operation Cycle of the Three-Level Neutral Point Clamped Inverter.

Output Voltage $V_{ao}$ (V)	Switch States			
	$S_{a1}$	$S_{a2}$	$S_{a1}'$	$S_{a2}'$
$V_{ao} = + V_d/2$	1	1	0	0
$V_{ao} = 0$	0	1	1	0
$V_{ao} = -V_d/2$	0	0	1	1

There are two circumstances. The switches are provided with switching pulses based on these circumstances. First, the sinusoidal wave magnitude must be more than zero, and second, it must be greater than the triangular wave magnitude. The two switches  $S_{a1}$  and  $S_{a2}$  are turned ON if the two requirements are met. The switches  $S_{a2}$  and  $S_{a1}'$  turn ON if any one of the conditions is broken. The two switches  $S_{a1}'$  and  $S_{a2}'$  are switched ON if none of the conditions are met.

Assume  $V_r > 0$ ;  $V_r > V_c$ ; as conditions A and B then for switch  $S_{a1}$ (A AND B),  $S_{a2}$  (A OR B),  $S_{a3}$  (A NAND B), and  $S_{a4}$  (A NOR B) are the appropriate logic. The logic for switches  $S_{a1}$  and  $S_{a2}$  are implemented and their inverse is applied to switches  $S_{a3}$  and  $S_{a4}$  respectively. The individual Switching scheme for each switch is shown in Table 2.

**Table 2.** Three Level NPC Inverter with Sine PWM

$V_r > 0$ (A)	$V_r > V_c$ (B)	$S_{a1}$ (A AND B)	$S_{a2}$ (A OR B)	$S_{a1}'$ (A NAND B)	$S_{a2}'$ (A NOR B)	Output Voltage (V)
0	0	0	0	1	1	$-V_{dc}$
0	1	0	1	1	0	0
1	0	0	1	1	0	0
1	1	1	1	0	0	$+V_{dc}$

$V_r$  - Voltage magnitude Reference Signal

$V_c$  - Voltage magnitude Carrier Signal

In this work, the analysis is made for NPC inverter with and without filters at the output AC side. So it is noticed that, Fig. 2 indicates a 3-level NPC Inverter without filter and the Fig. 3 indicates a 3-level NPC Inverter with filter circuit.

The selected filter is an L-C filter with the following values:  $L = 21$  mH;  $C = 470$  uF. Figures 8, 9 and 10, respectively, display the line-to-line output voltages for the three-level NPC inverter of sine PWM without and with filters. The aforementioned circuits were successfully simulated in the MATLAB-SIMULINK software. Using the POWERGUI tool in MATLAB-SIMULINK, FFT analysis is performed to determine the harmonics. The individual harmonics along total harmonic distortion for 3-Level NPC inverter without and with filters are shown in Fig. 4 and Fig. 5 respectively.

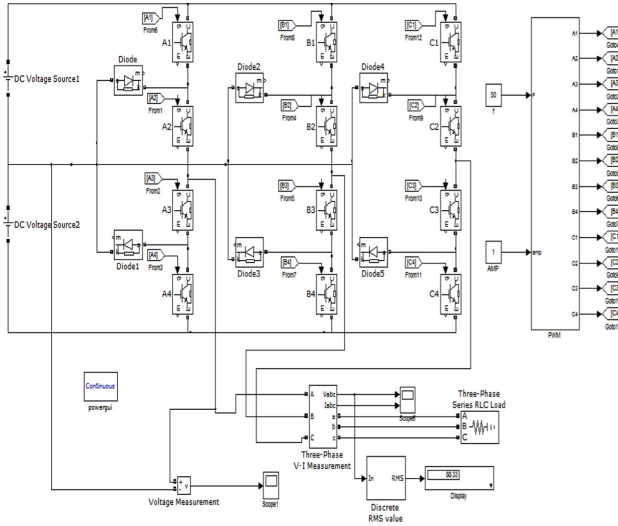


Fig. 2. Diagram of a three-level NPC inverter in SIMULINK without a filter

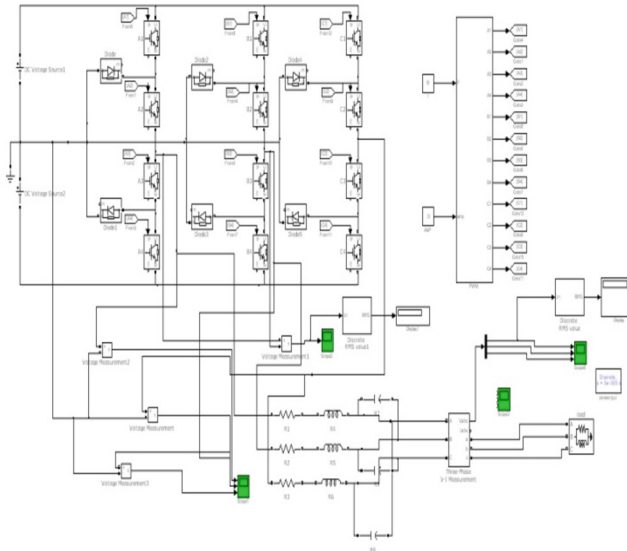
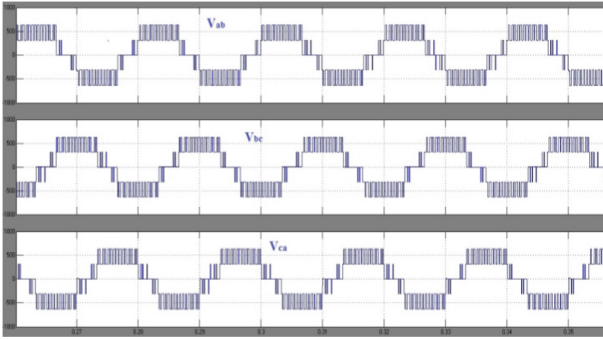
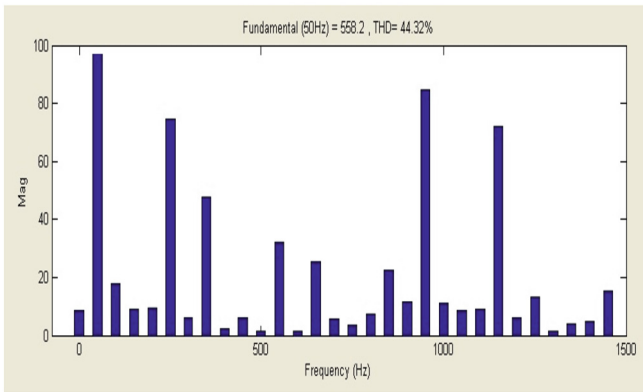


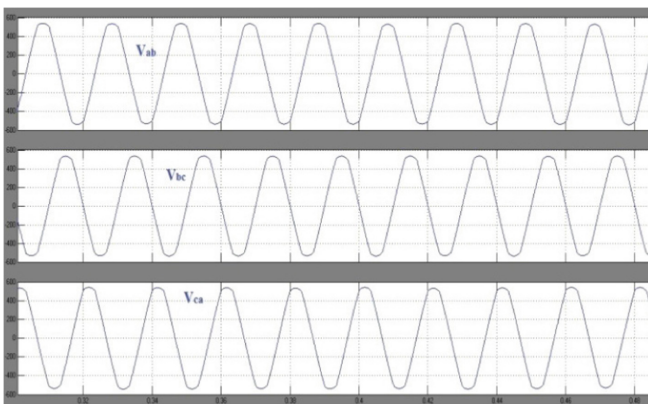
Fig. 3. Schematic of Three level NPC inverter with filter in SIMULINK



**Fig. 4.** Voltages across lines of a three-level NPC inverter using sinusoidal PWM and no filter



**Fig. 5.** THD of output line voltage of 3-level NPC inverter with SPWM and without filter



**Fig. 6.** Three-Level NPC inverter line to line voltages with sinusoidal PWM and filter



The obtained line to line voltages for 3-level NPC inverter of THIPWM without and with filters are shown in Fig. 10 and Fig. 11 respectively. Similarly as in case of SPWM, here also harmonic calculation is made by performing FFT analysis and it is shown in Fig. 9 and Fig. 10 for 3-level NPC inverter of THIPWM without and with filter respectively.

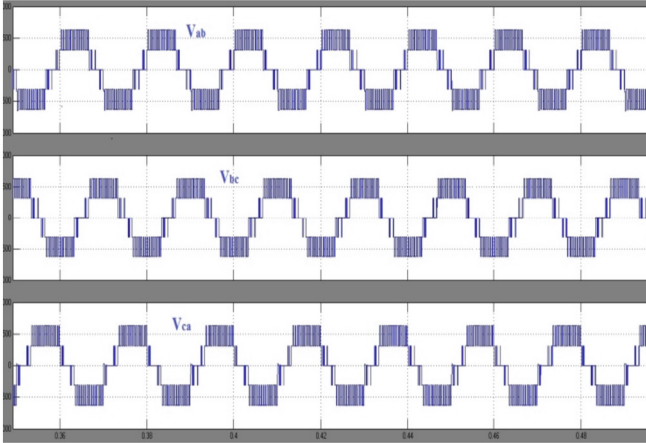


Fig. 9. Voltages across lines of a 3-level NPC inverter with THIPWM and without a filter

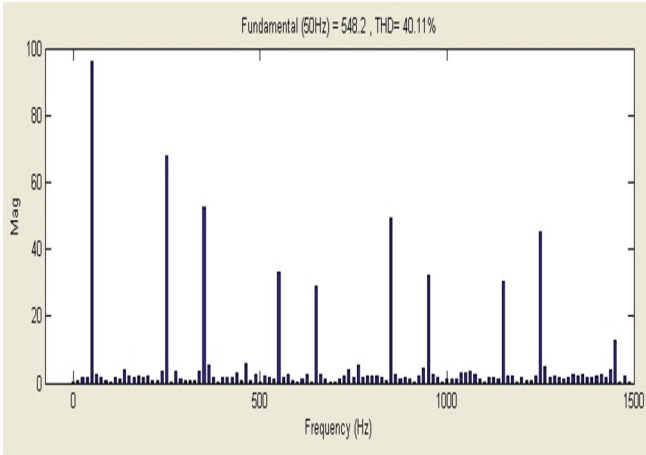
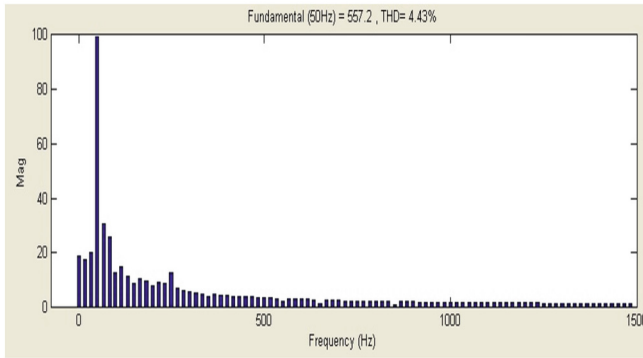


Fig. 10. THD of line voltage of 3-level NPC inverter with THIPWM and without filter

### 3.1 Comparison Between Sine PWM and THIPWM

From Table 3 it is observed that, the third harmonic injection PWM [14] not only reduces the amount of voltage THD, but also reduces the usage of input DC voltage. It can produce



**Fig. 11.** FFT analysis of line voltage of 3-level NPC inverter with THIPWM and with filter

**Table 3.** Comparisons between Modulation Techniques

Parameter	Sinusoidal PWM			THIPWM		
	DC I/P	Output line voltage	Voltage % THD	DC I/P	O/P	Voltage % THD
<b>Line voltage without filter</b>	620	420	44.32	510	428	40.11
<b>Line voltage with filter</b>	620	408	10.29	510	415	4.43

nearly same output Line Voltage of 415 V even if 15.5% input voltage is not available as compared with sinusoidal PWM. It is noticed that, the simulation process is conducted at modulation index of 0.75. The power quality [15–19] is mainly improved with the reduction of total harmonic distortion.

## 4 Conclusion

The three-level Neutral Point Clamped inverter is simulated in MATLAB-SIMULINK utilising sinusoidal PWM and third harmonic injection techniques. Third harmonic injection PWM has been shown to lower an SPWM's output THD from 44.32% to 40.11%. Additionally, the THIPWM approach is lowering the output voltage THD for the same inverter with filter from 10.29% to 4.43%. Finally, it is clear from the data that the THIPWM approach reduces overall harmonic distortion while also making appropriate use of the DC input voltage.

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